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Visual Troping and Scientific Truth:
Unwinding DNA

by

Katharine Charlton

A thesis submitted to the Department of English
in conformity with the requirements for
the degree of Master of Arts

Carleton University
Ottawa, Ontario, Canada

November, 1999

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"Visual Troping and Scientific Truth: Unwinding DNA"

in partial fulfillment of the requirements for the degree of Master of Arts

A handwritten signature in black ink, appearing to read 'R.B. Rutland', is written over a horizontal line.

R.B. Rutland, Thesis Supervisor

A handwritten signature in black ink, appearing to read 'L. R. McDonald', is written over a horizontal line.

Chair, Department of English

Carleton University

7 December 1999

Thesis Abstract

This thesis is an examination of the importance of figurative language in scientific discourse. In particular, the role of diagrams is examined, such as the one included in James Watson and Francis Crick's 1953 paper, "A Structure for Deoxyribose Nucleic Acid." This figure is an example of a visual trope that supplements the written text and increases its persuasive effect by appealing to cognition.

The first section of the paper discusses the historical context of the Watson-Crick paper. The second section is a review of the literature that responds to "A Structure;" literature written by scientists, historians of science, and scholars studying the rhetoric of the paper. The third section discusses Hayden White's ideas of troping and the inability of scientific discourse to escape figurative language, as well as the application of these ideas to visual aspects of rhetoric. In the fourth section, the role of the DNA double helical diagram is examined, and the role of figures as essential supplements to written text. The final section realizes the influence of visual rhetoric through its relation to cognition, using Lakoff and Johnson's concept of embodied perception from *Philosophy in the Flesh*.

Many thanks to my advisor, Barry Rutland, for all
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I

James Watson and Francis Crick's unveiling of the spectacularly elegant structure of DNA in 1953 is one of the most well-known pinnacles of twentieth century science. Previously unrecognized, they were the unknown variables, the long shots in a competitive race. Their achievement, however, was neither luck nor scientific brilliance alone: though these elements were involved, they do not form the whole composition of their discovery and its impact. The structure was much anticipated in the scientific community, which made their paper timely and ensured that attention was paid to it. Their argument was also brief and succinct, ensuring that none of the most important features or implications would go unnoticed or overlooked in a sea of data. Their emphasis also centered the paper precisely between the history of research on DNA and the future: their argument, largely theoretical, mobilized already established but unsynthesized information about DNA; and the paper ends with a suggestion of the

implications of the DNA structure, namely, that the base pairing indicates a copying mechanism that further research could likely illuminate. Watson and Crick, then, not only presented an acceptable structure, but presented it at the right time, and in the right manner.

Interest in DNA had been initiated almost exactly a century before the discovery of its structure. Horace Freeland Judson notes that, in the mid-nineteenth century, scientific interest was beginning to move away from organs and tissues to the unit of the cell (7-8). Biochemists had isolated the four main molecular components of the cell: carbohydrates^{*1}, lipids*, proteins* and nucleic acids*. In 1868, Johann Friedrich Meischer collected discarded surgical bandages to obtain pus for experiments. Pus is largely composed of white blood cells*, which have large nuclei and little cell matter. From the pus, Meischer isolated a substance that he named "nuclein." The major features that he observed about nuclein were that it was an acidic substance*, that it was rich in phosphorus*, and that the molecules were large (Judson, 11).

In 1870, using salmon sperm, Meischer extracted pure DNA. In 1889, his pupil Richard Altmann exchanged "nuclein" for the more chemically specific name "nucleic acid" to signify DNA (Judson, 11). Because the study of large molecules was relatively new, Meischer made general and preliminary discoveries about the structure. However, he did recognize that DNA was

¹ Words marked with stars are defined in the glossary, found at the end of the paper, preceding the works cited.

composed of repeating units and Judson quotes one of Miescher's interesting early observations from 1892:

...some of the large molecules encountered in biology, composed of a repetition of a few similar but not identical small chemical pieces, could express all the rich variety of the hereditary message, "just as the words and concepts of all languages can find expression in twenty-four to thirty letters of the alphabet." (12)

In addition to foreshadowing one of the major features of the structure of DNA as Watson and Crick present it, Meischer's comparison introduced the structure of language to explain the function of DNA, a metaphor which has become pervasive.

In Meischer's time the function of the nucleic acids in the cell were largely unknown. His students and other researchers provided more specific chemical information about DNA, including the main components. They identified a ribose sugar*, a base*, and a phosphate* that links the sugar-base units.

In the 1920's, more exact information revealed the chemical differences between DNA and RNA (Judson, 12). One of the differences is that RNA has a ribose sugar*, where DNA has a deoxyribose sugar*. The other difference is that, of the five significant bases, DNA and RNA each have four. Common to both are guanine, cytosine, and adenine; DNA's fourth base is thymine, whereas in RNA, the fourth base is uracil.

In the early 1930s the tetranucleotide hypothesis was introduced by Phoebus Aaron Levene, an organic chemist at the Rockefeller Institute for Medical Research in the United States. This hypothesis claimed that DNA was built in the simplest way possible, with nucleotides following each other in repeating sets of four. At that time, and indeed until 1951, the genetic material was believed to be protein, not, as we know now, DNA. The tetranucleotide hypothesis proposed a function for DNA as something like a backbone for the genetic material, a molecule to give structure but not participate in heredity (Judson, 13-14).

In February of 1944, Oswald Avery, at the Rockefeller Institute of New York, published a paper that concluded that “a transforming principle” (Judson, 19) was the hereditary material, and that this material was not made of protein. Though Avery’s results indicated a substance closely resembling nucleic acid, he could not account for some chemical discrepancy and so, in the paper, suggested DNA as the “transforming principle” but did not conclude this emphatically, as he did later in a personal letter (Judson, 22).

These conclusions were not accepted at the Rockefeller and instead prompted more complex questions about *how* DNA could function as the genetic material if it were not made of protein (Judson, 22). However, Avery’s paper was later influential and recognized as correct and Judson compares this lengthy, exhaustive but untimely and largely overlooked paper with the Watson and Crick paper which had caused such immediate impact. Judson finds the Avery

paper premature with respect to the Watson-Crick paradigm shift; though it is lacking both the style and timeliness of “A Structure for Deoxyribose Nucleic Acid,” it most importantly lacks confidence:

Avery’s concluding discussion is one of those precursors that can sometimes be looked back to in science, or for that matter in philosophy or economic theory or painting, where one seems to see an idea struggling to shake free from a net of previous conceptions. (Judson, 20)

Erwin Chargaff, inspired by the question of *how* DNA could function as the hereditary material, actually changed the work of his laboratory from biochemistry to focus on nucleic acids. He published data that contributed to the knowledge on DNA. Though his 1950 paper was widely read, Chargaff himself did not fully recognize the implications of his results, though his conclusions became an important component of the information that Watson and Crick synthesized. “Chemical Specificity of Nucleic Acids and their Enzymatic Degradation” found that DNA bases occur in regular ratios depending on the species, but always with the amount of adenine roughly equal to the amount of thymine and the amount of guanine roughly equal to cytosine. This observation is known as the “Chargaff Ratios” and was important in displacing Levene’s tetranucleotide hypothesis. If the bases strictly followed one another, the ratios would have been found to be equal for all the bases, each base accounting for 25% of the total. Instead, in different species entirely incompatible ratios were

found, such as in human DNA: the proportion was 28 parts adenine, 28 parts thymine, 16 parts guanine, 16 parts cytosine. To have these different proportions also made it explicit that, instead of one DNA of repeating units, there must be many variations of DNA with different proportions and sequences of bases (Judson, 74).

At this point in the early 1950's interest in DNA was intense, with particular fervor concentrated on the question of how DNA functions. The basic chemical knowledge that was crucial to Watson and Crick's paper was available but had yet to be synthesized into a coherent explanatory theory. Competition in DNA research arose, motivated by the assumption that the structure could somehow illuminate the function. Thus, a number of researchers began to investigate the structure in earnest, creating excitement, expectation, and anticipation--an atmosphere that readied a space for the Watson-Crick paper to counter, unlike the struggling of the Avery paper, the tide of old knowledge.

A model of DNA became the goal; the knowledge that others were simultaneously working on the project accelerated research. Three main groups shared the same desire to reach a model of DNA first. Each approached the problem with a different method, all were reluctant to share information, and consequently all felt the pressure of uncertainty. The race was both progressive: *for* the structure; but also relative: *against* the other scientists. The important competitors, at this stage, were Linus Pauling; Maurice Wilkins and Rosalind Franklin; and, with Max Perutz, Watson and Crick.

Previous to the "A Structure for Deoxyribose Nucleic Acid," James Watson and Francis Crick were unrecognized scientists in the emerging field of molecular biology. Watson was a bright pupil of Max Delbruck's, a Caltech scientist whose research on hereditary material involved studying the relationship between genes and viruses, specifically bacteriophages, viruses that infect bacteria. In 1951, as a postdoctoral fellow, Watson began research in Copenhagen, working on nucleoproteins. He remained interested in the gene and was unconvinced that DNA was made of protein. In September of that year he joined researchers with similar ideas at Lawrence Bragg's Cavendish Laboratory at Cambridge.

Francis Crick was originally trained as a physicist but became interested in what he thought of as "the physics of biology" (Judson, 88) and moved to Bragg's Cavendish Laboratory in 1949 as a doctoral student in order to pursue the overlap between the two fields. He learned protein crystallography and worked with Max Perutz on the structure of hemoglobin, remaining curious about "the relation of gene structure to protein structure" (Judson, 90). Watson's arrival and his similar interest allowed Crick to redirect his attention, and together they began work on the structure of the genome. As a team, Watson and Crick were an additive, emergent unit that was more than the simple sum of two people working on the same project. Their collaboration during 1951-1953 was energetic and earnest, with Crick's knowledge of physics and crystallography complementing Watson's knowledge of biology.

This contrasts with the unsatisfying partnership of Rosalind Franklin and Maurice Wilkins at King's College, London. Wilkins' primary research focus was the intricate structure of hemoglobin, a large and complex molecule comprised of approximately ten thousand atoms and of considerable biological interest because of its role as the oxygen carrying component of red blood cells. His involvement in DNA was primarily an extension of this interest in the structure of large molecules and the use of x-ray crystallography to determine these structures. Franklin, working in Wilkins' laboratory, used the relatively new methods of x-ray crystallography to pursue the structure of DNA. Tension resulted in their collaboration over what Franklin had been hired to work on and whether she was directing the project on DNA's structure. Eventually Franklin felt protective of her work and became solitary about her research.

The two English groups were well aware of each other; however, both sides were reluctant collaborators. Wilkins, though friendly toward Watson and Crick, had increasingly little information about Franklin's research. Though Franklin's x-ray photographs confirmed for Watson and Crick the double helical shape of DNA, their approaches to the problem were different. Franklin pursued DNA through x-ray crystallography, a painstaking process of photographing patterns in molecules that requires considerable mathematical analysis. Watson and Crick, armed with the basic chemical composition of DNA, emulated Pauling and concentrated on the physical, three-dimensional possibilities and so approached the structure through model building. Each side held the other in

slight disdain: Franklin found the model-building childish and reductionist; Watson and Crick found x-ray analysis too slow, too abstract, and useful for confirming hypotheses but not for forming them.

This mild animosity culminated in late November 1951, when Watson and Crick unveiled a structure to Maurice Wilkins and Rosalind Franklin. In this proposed structure, Watson had correctly surmised the helical pattern from x-rays that Franklin had shown him. Franklin had interpreted her crystallography pictures differently and was unconvinced that the structure was helical. At first she proposed in her notebooks “a double-sheet structure of banana-like units,” which she later abandoned for an alternative “figure of eight structure” in January 1953 (Judson, 132). But in their 1951 proposal, Watson and Crick made a more fundamental error: Watson had recalled the water ratios inaccurately when he and Crick built the structure. It was on this point that Franklin, annoyed at being called from London to examine a clearly faulty structure, quickly dismissed it. As a result, Bragg forbade Watson and Crick to proceed with further work on the DNA project. They disobeyed him, however, and continued; but, until the spring of 1953, their work was erratic in intensity.

Also working on the problem of DNA was the renowned and formidable chemist Linus Pauling, who by 1951 had already received a Nobel Prize for “research into the nature of the chemical bond and its application to the structure of complex substances” (Goertzel, 133). Pauling was something of a scientific

impresario. He ran a number of projects in several Caltech² laboratories and had an intuitive ability with structures, proven by his research on proteins. Pauling contributed indirectly to the resolution of the DNA problem through his book *The Nature of the Chemical Bond*, studied by Watson and Crick, and also by pioneering the technique of model-building that Watson and Crick used.

Pauling's political activities, chiefly in protesting nuclear testing, attracted the attention of the McCarthy investigations. As a result, in April 1952 he was refused a passport. This caused a scandal that received media attention and Pauling was given a passport with restrictions, but he still missed his visit to a Royal Society meeting in London at the end of April. The meeting was on the structure of proteins and Pauling would have almost certainly seen Wilkins' and Franklin's x-ray pictures of DNA (Judson, 54). Speculation that Pauling, had he been permitted to travel to England in 1952, would have elucidated the structure of DNA varies in confidence from certain to unlikely. Robert Olby championed Pauling:

[he] felt sure that if Pauling had made that trip [April 1952], Wilkins would have shown him something. He also said that most people believe that Wilkins, given sufficient time, would have arrived at the double helix structure for DNA. Olby would like to add (June 1970) that he has recently seen the x-ray diffraction photographs taken after Pauling's suggested structure for DNA

² California Institute of Technology, in Pasadena (LA), California.

had been published. These photographs...show considerable detail...if a camera designed for fiber work had been available, plus an appropriate x-ray source--or if Pauling had had access to Wilkins' photographs--he would then *no doubt* have had the data in his hands on which to base a correct model for the structure of DNA. (1009n, "Fifty Years of Progress..." emphasis added)

On this point, Judson quotes Wilkins from an interview: "...if people want to speculate about, 'Well, if Watson and Crick hadn't got it, who would?' then I think I could make a good case. As good as anybody's" (80).

Others also express doubt on the likeliness that Pauling would have arrived at the structure, including his biographer Goertzel, and Judson, author of the respected and comprehensive *Eighth Day of Creation*, a history of biology. Perhaps most significant is Pauling's own reflective admission to Judson that "we [Pauling and Corey] weren't working very hard at it. We had really very little...of our own experimental data, a few rather poor x-ray photographs of DNA, not carefully prepared" (70).

However, Pauling and his associate Robert Corey published a paper in the *Proceedings of the National Academy of Sciences* on 21 February, 1953, just months previous to the Watson and Crick paper. The Pauling-Corey paper was seen by Watson and Crick previous to its publication because Pauling had mailed a copy to his son, Peter, also in Cambridge at that time and a colleague of Watson and Crick. But this paper proposed an incorrect triple stranded model that also had

a fundamental chemical error, recognized immediately by Watson and Peter Pauling. The inaccuracy of this model was a relief to Watson and Crick and they redoubled efforts to realize the structure. Judson notes that

three things about Pauling's paper were striking...it was uncharacteristically tentative...the paper was also--how strange--entirely synthetic: Pauling offered no new data of his own about DNA...the paper appeared to claim a structure correct for the nucleic acids generally, meaning RNA as well--a claim that was biochemically bizarre. (134)

The model also had three substantial faults: first, the atoms at the core of the helix were packed together too closely; second, "the hydrogen bonds that held Pauling's triple helix together at the core made chemical nonsense. They required that the phosphate groups be filled in with extra hydrogen charges, to connect the P---O....H---O---P, canceling the local electrical charges, with the result that 'Pauling's nucleic acid was not an acid at all'; and thirdly, "the model stood mute. It explained nothing at all. It gave no clue to its own reduplication, nor to its influence over the rest of the cell. In particular, the structure was ignorant of Chargaff's rules"³ (Judson, 135).

Watson and Crick, on Friday, 27 February, completed the research that was later published as "A Structure For Deoxyribose Nucleic Acid." The

³ i.e., the most important evidence for the base pairing proposed by Watson and Crick, and the key to the structure's form (regular, repeating alpha helix) and function (of replication).

following week their molecular models were completed by the machine shop at Cambridge and they built the structure that they had envisioned. On 12 March, Watson wrote to Delbruck; on 17 March, they completed a rough draft of their paper; on 19 March, Crick wrote to his son; and on 21 March they wrote together to Pauling. During this time Wilkins and Franklin both visited the Cambridge lab, Pauling at the beginning of April. Finally, on 25 April, the paper was published in *Nature*, one of the most influential and prestigious scientific journals.

Scientifically, the most significant observations of the paper were that the phosphates must be on the outside of the helix in order to be easily accessible to cations (positively-charged ions); that the bases must be in the keto* rather than the enol* configuration; and that the base pair ratios proven by Erwin Chargaff relate to the copying mechanism. Previously, the alpha helical structure was known and even some of its dimensions, but how the bases and phosphates were arranged was not. Chargaff had proposed the relative ratios of the bases as 1:1 between A-T, C-G, but had not elaborated on the implications that these ratios had for copying, though the perplexing ability of DNA to replicate was demonstrated by earlier experiments such as Avery's.

The scientific observations envisioned by Watson and Crick and then built into a model had to be built, finally, into a paper to explain and proclaim their findings to other scientists. The writing of a paper, an essay, follows the collection and analysis of data and is the building of a rhetorical argument. Thus

the paper transgresses the boundaries of a simple relationship between data and claim; elements of rhetoric are added to “pure science.” Watson and Crick do not merely provide a series of data for the reader to interpret; rather, the data is pre-interpreted and arranged by them in the form of a rhetorical argument. The analysis of the visual aspects of the paper, traditionally regarded as extrascientific or even as antiscientific, are also illuminating. It is worth noting that Watson and Crick did not provide a great deal of new data (one of Judson’s criticisms of Pauling and Corey’s faulty paper), but that their inferences were largely based on data that already existed and was accepted by the scientific community. Therefore their synthesis of these data into a rhetorical argument was less a scientific leap of faith than linear movement along already solid ground. In order to do this, their rhetorical achievement was inseparable from their scientific one. Perhaps the most important point about the rhetorical strategy is precisely that little new data were provided; indeed, Judson points out the implications of providing a theoretical argument without scientific proof:

The model that Watson and Crick had devised, despite its physical presence standing there on a table in the corner of a room at the Cavendish Laboratory, had its only significant status as a theory--a theory in the neutral, nonperjorative sense in which Francis Crick, or Albert Einstein for that matter, was a theoretician. The model of DNA *was a proposal about the physical nature of a biological substance*. The proposal had consequences: if it were false, certain things

should fail to be found by experiment, and the first scientific purpose of the series of papers was to elaborate what the consequences were so that the model, the theory, could be tested. (161, emphasis added)

The “series of papers” that Judson refers to are the four papers and numerous talks that Watson and Crick wrote and gave *following* the publication of “A Structure” in the four months that passed until Rosalind Franklin provided corresponding crystallographic evidence.

That the argument was primarily theoretical makes it an unusual candidate for such rapid acceptance by the scientific community, as indeed it was, indicated by the remarkably short amount of time before Watson and Crick, with Maurice Wilkins, were awarded the Nobel Prize for their research (1962). The theoretical nature of their argument and the implications of the last line of the paper: “it has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material,” provided the opening for much work to be done by scientists, and the paper itself is often targeted as the birth of molecular biology as a subdiscipline of science.

There is one element of their rhetoric that is often overlooked--the inclusion in their paper of a simple diagram of the DNA structure. Elegance in scientific experiments is highly prized and the ability to propose a simple yet apparent model is an underestimated advantage to Watson and Crick’s

argument. Because of its shape, the diagram is readily understood as a representation of the structure, even though base pairs and exact dimensions are excluded. Some of the most important features remain obvious, such as the general shape of the molecule, the opposite strands, and the potential for copying that the two strands provide in that they are independent of each other. Yet any molecular model is only a metaphor (a “proposal”) for a much more complex and unimaginable structure that physically exists. Watson and Crick’s figure of DNA is a map of the features of the molecule, not a direct re-presentation of the molecule itself. They acknowledge this mapping near the end of the paper: “full details of the structure...together with a set of coordinates for the atoms, will be published elsewhere.” By including such a diagram in their paper, Watson and Crick provide a visual trope that reiterates the content, and also embodies the elegance and common sense of their rhetorical argument. Though they excuse the figure as “purely diagrammatic,” it, as a representation, has rhetorical power. Their data are organized by means of a persuasive visual trope, providing an important, immediate dimension to the diataxis.

Here science relies conspicuously on representation. The simple diagram evokes art, drawing, architecture--methods of visual display that make key features readily apparent. But the visual aspect was central to conceptualizing the molecule’s structure from the beginning: Franklin sought the structure through pictorial, photographic representation and mathematical analysis, while Watson and Crick preferred to follow Pauling’s protocol of using physically

approximate three dimensional models of atoms and chemical bonds. Both of these methods are ways of representing physical reality; both rely on visual and spatial sense. Judson asserts that

Watson stumbled on his part of the solution visually, from a shape, a representation, and that had happened several times before; that is the way his mind works. No two of the four kinds of bases [adenine, guanine, cytosine, purine] have the same contour. Watson found that the purine adenine, a fused double ring with other atoms fringing it at several points, could form two hydrogen bonds with the pyrimidine thymine, a single ring, when he placed the two cutouts side by side in the right way. The bonds were the correct length, and were straight lines, N---H...O or N...H---N, as Pauling's model-building precepts required. Guanine and cytosine made hydrogen bonds the same way. The pairing could not be switched, however, for then the various atoms around the fringes got in each other's way. But when an A-T pair was laid on top of a G-C pair, the two compound shapes were exactly congruent. Such pairs could fit inside the backbone without bulges or pinches.

(149, emphasis added)

Crick, in a letter to his son, writes, "we have built a model for the structure of des-oxy-ribose-nucleic-acid (read it carefully) called D.N.A. for short...our structure is very beautiful" (Judson, 153). Even Erwin Chargaff, one of the

outspoken opponents of the structure, admits that it was “an aesthetically pleasing solution” (*Voices in the Labyrinth*, 59). Its simplicity and beauty seemed to reinforce its correctness, as implied by Watson’s statement, “a structure this pretty just had to exist” (*The Double Helix*, 120).

II

“A Structure For Deoxyribose Nucleic Acid” inspired a great deal of scientific experimentation, first to determine the correctness of the theoretical structure, and later to follow up the rich implications of the final sentence of the paper: “it has not escaped our notice that the specific pairing of the bases we have postulated immediately suggests a possible copying mechanism for the genetic material” (737). Initially, a discourse specific to the scientific community arose, dedicated to the experimental and technical details of proving and modifying Watson and Crick’s postulations on the structure. Yet writing about DNA did not remain in this specialized realm. Notably, interest in the history of science focused on the context and timing of this seminal paper, both by scientists and nonscientists. Another secondary interest became the paper itself and its rhetorical strategies.

Of the history written by scientists, *The Double Helix*, James Watson's 1968 account of the events surrounding the discovery of the structure, was both famous and infamous; it was found to be at once fascinating, inflammatory, and validating to other scientists. It was also a popular book with the public in general, who were acquainted at least with the idea and possibilities of DNA: by the time of the book's publication, Watson and Crick had been awarded a Nobel Prize, the structure had entered science curricula, and controversial work on the genetic code had begun.

Crick also published a less heady account of the history in a special 1974 issue of *Nature* that dedicated a part of the journal to reflecting on the 21st anniversary of the double helix. He offers insight into the much discussed last line, explaining that a difference in confidence between himself and Watson prevented their elaborating the point. Crick also acknowledges model building as a key to their discovery, and evaluates faults with the paper ("the structure is produced like a rabbit out of a hat"). Significantly, he also acknowledges the importance of timing, style, and method in the impact that the model had on the scientific community: "...if Watson and I had not discovered the structure, instead of being revealed with a flourish it would have trickled out and its impact would have been far less." It is in this article that he makes the much quoted statements that "it is the molecule which has style, quite as much as the scientists," and "rather than believe that Watson and Crick made the DNA structure, I would rather stress that the structure made Watson and Crick" (768).

These statements acknowledge, in retrospect, a degree of seeming arbitrariness in science that is related to style and persuasion: the scientist is a rhetorician, a master of information and how to manipulate and gauge the momentum in the community in order to reveal the information with maximum impact.

Pauling also writes on the history of science in a *Daedulus* article of 1970 called "Fifty Years of Progress in Structural Chemistry and Molecular Biology." This is his account of much more than DNA, indeed, of all the science that spans his capacious and lengthy scientific career. In relation to DNA he recounts his attempts to work out the structure and acknowledges his mistakes. As a prestigious scientist, active and intellectually prolific for many years, his mature reflections have the authority of a first-hand expert. Pauling's attitude is one of evaluative fairness; he records his pleased surprise at the simplicity of the structure with the sincerity of one who likes to see a puzzle satisfactorily resolved, and, most importantly, he acknowledges the discovery as an influential moment: "the discovery of the DNA structure by Watson and Crick has had a tremendous impact on molecular biology" (1010).

Perhaps the scientist most vehemently opposed to the work of Watson and Crick was Erwin Chargaff. In "Building the Tower of Babble" he refers to them disdainfully as "two pitchmen in search of a helix" (*Voices In The Labyrinth*, 55) and remarks that "the publicity carnival that ensued on the unveiling of the DNA model was probably unique in the history of science" (60). Chargaff, like Crick, also raises the question of charisma; however, he considers it a negative

factor in science. He objects to personality cultism, arguing that “it is not the men who make science but science that makes the men...what A does today surely B or C could do tomorrow” (12). Chargaff finds science too commercialized and subjective, and suggests that truly inquisitive experimentation has been replaced by cost-conscious, extraordinarily expensive science, resulting in “normative biology that command[s] nature to behave in accordance with the models” (59). These points, though partly the bitterness of a traditional scientist who objects to change, nevertheless raise important issues of subjectivity, acceptance of claims, and the questioning of empirical methods.

The history of the DNA discovery has also been examined by scholars who are not scientists. Horace Freeland Judson, who became interested in science after occasional science reporting duties as a journalist, provides a comprehensive history of twentieth century biology in *The Eighth Day of Creation: Makers of the Revolution in Biology*. He begins his discussion with a thorough 171-page section titled “DNA Function and Structure: The elucidation of the structure of deoxyribose nucleic acid, the genetic material.” He writes for the uninitiated, explaining the science as he retrospectively organizes scientific history, interspersed with interviews with key people. He conveys a many-faceted, thoughtful and informed account of events, with a sense of the scientists’ involvement, their personalities, and their reflections on the scientific changes in which they participated.

Robert Olby is another who has contributed to the history of science. Like Judson, he is interested in how the personalities and intellectual styles of the scientists affect their work and involvement in projects. In 1970, he published "Francis Crick, DNA, and the Central Dogma," an exhaustive examination of Crick's scientific career, beginning with the intellectual frustrations of his upbringing, his education and his early appointments, through collaboration with Watson on DNA to his subsequent work on the genetic code. Olby scrutinizes Crick's personality and how his creativity and methods affect his scientific work. In "DNA before Watson-Crick," Olby also provides a more traditional history of development on DNA research, detailing the tetranucleotide hypothesis, the establishment of macromolecular DNA in the 1940's, and tracing the influence of the Avery experiment. He also considers the contribution of Chargaff and the overthrowing of the tetranucleotide hypothesis that was possible because of chromatography techniques. The article finishes with a history of Watson's involvement as a student in Max Delbruck's Phage Group at Cold Spring Harbor.

Other nonscientists who examine "A Structure for Deoxyribose Nucleic Acid" include rhetoricians, who are interested in the argument of the paper and its relationship to scientific and other genres of discourse. Timing is a consideration, as with the historians, but as an aspect of persuasion, a tool to make the argument more effective. Likewise, this thesis concentrates on another rhetorical device: how the diagram included in the paper is persuasive. Most

commonly, rhetorical studies scrutinize the language and organization of “A Structure,” examining the ways in which the argument is constructed to achieve its powerful persuasive effect.

Lawrence Prelli, in *A Rhetoric of Science*, finds the argument of “A Structure for Deoxyribose Nucleic Acid” interpretive, given the work that already existed on DNA. He discusses this synthesis of existing information, rather than presentation of new data, as a rhetorical strategy that has become important in twentieth-century scientific methodology. He pinpoints a key element of the argument: though the model is meant to be understood as a “proposal of the physical world,” Watson and Crick state that it is “not *like* a double helix but *is* a double helix” (243). This is an important contribution in that Prelli realizes the implications of a simple and elegant model: that it can be taken as a one-to-one ratio, the model to the physical world.

This acknowledgment of the representational and thus fictional aspect of the model is continued by Alan Gross in *The Rhetoric of Science*. He evokes the fictional aspect of history even in the title of the section dealing with the Watson-Crick paper: “A *Tale* of DNA” (54, emphasis added). He insists that knowledge is arrived at by many different ways, and as an example compares the “Structure” paper to Watson’s *The Double Helix*. He makes a subtle analysis of the interpretive elements of the paper, already noted by Prelli. Gross states, “a molecule of this structure exists...but the sense of its reality is an effect of words, numbers, and pictures judiciously used with persuasive intent.... Watson and

Crick's interpretation *in* words and pictures is an interpretation *through* words and pictures" (64). This representational hall of mirrors is an important aspect of scientific rhetoric and often neglected due to a long cultivated acceptance of scientific language as pure truth or fact rather than persuasive argument. Gross also notes that describing the molecule takes up most of the paper, and that the foundation for Watson and Crick's knowledge is primarily visual, from photographic evidence. This is also important in the context of considering the model as part of the rhetorical strategy of the paper. The relation between photographic and physical reality is not immediate and unproblematic, but requires an act of interpretation--in this case, primarily mathematical, though still based on vision--the ability to see and measure distances in the obtained photographs, for example. However, our faith that the photograph exactly corresponds in a one-to-one ratio must be questioned; as an illustration of this, consider an example from film. In Antonioni's *Blow Up*, a photographer believes he has inadvertently witnessed a murder, so he examines the photographs he was taking at the time. Unable to determine what occurred, he enlarges the photographs, searching for clues, details, truth...and is confronted with only increasingly ambiguous gray images.

Michael Halloran evaluates the rhetoric of the paper in relation to its significance. He finds that it has confidence and "a genteel tone" that gives it an unusual personal voice, and creates an image of a scientist speaking through this "rhetorical persona" (43). It is important to analyze this aspect of persuasion, he

argues, because of the importance of the paper itself. Halloran calls it an “extremely prominent twentieth century document, one which virtually invented a science” (xxxix), and, more emphatically, asserts that “more clearly than any single scientific paper in recent years, this one stands near if not precisely *at* the center of what Thomas Kuhn would call a scientific revolution” (39). The historical importance of the paper justifies its scrutiny; most significant are the features of the paper that have led to its rapid acceptance and monumental status. Halloran also takes note of the elegance of the model, and adds the important point that Watson and Crick make a negative argument that the model is not inconsistent with any existing data.

The scientific importance of the paper is therefore well recognized, as well as its cultural impact. Yet how this impact happened rapidly and profoundly in relation to shifts in twentieth century science is not elaborated. The rhetoric of the paper is discussed in depth; the elegance of the model is discussed in depth, but the relevance of the model to the rhetoric is left underestimated. The diagram itself is part of the paper, a visual trope that is no less important than the linguistic tropes required to construct the argument. Furthermore, the use of visual tropes (as representations of data) are increasingly important in twentieth century scientific discourse. Diagrams, graphs, and molecular drawings are efficient and often elegant ways of displaying data, results, proposed structures: they are also persuasive. The tendency is to treat models and diagrams like photographs, as having a one-to-one relationship between the representation and

the physical object. Instead they are proposals for “maps” of physical reality, but they are no more than *approximate* representations of phenomena that can not be represented exhaustively or with complete accuracy. However, in the context of the paper, these figures are supplementary to the verbal and mathematical text because their apparent primary function is to reiterate the main text in a reduced and simplistic form. In terms of the persuasive argument, though, these figures become an integral part of the symbiotic relationship of the supplement.

Derrida discusses the supplement as something that “adds itself, it is a surplus, a plenitude enriching another plenitude” (144). It *seems* to have a separate and additional existence. Derrida warns: “there is a fatal necessity...that the substitute make one forget the vicariousness of its own function and make itself pass for the plenitude of a speech whose deficiency and infirmity it nevertheless only *supplements*” (144). Therefore, the diagram of DNA *seems* supplementary, external, additional; however, the existence of the diagram depends upon the paper. It is not self-sufficient; it requires the accompanying explanation. It is a supplement to representation, and is representation itself; importantly, it is reiterative of the paper and not a previously existing example drawn from the physical world.

This assumption that a figure is somehow independent of the written text gives the model or diagram an authority of representation that we no longer acknowledge as one of language’s possibilities. Thus, it becomes of utmost importance to examine the shift in twentieth century scientific discourse towards

more diagram- and model- based arguments, to realize that these forms have an unrecognized and arbitrary authority over and above the written text, and that the shift toward these models is possible because of the changes in the twentieth century that privilege the visual and acknowledge the subjectivity of the observer. In particular, the rapid acceptance and pervasive influence of the Watson and Crick paper indicates that it stands at a crucial point in this shift. Their strategy exploits these changes in discourse conventions, and, because of the success of the paper, becomes an important rhetorical model.

III

The way that we understand DNA has a relationship to the way it is explained and taught. It is almost always described by the metaphor of DNA as language. Crick writes, “[DNA] ...is like a code. If you are given one set of letters you can write down the others. Now we believe that DNA *is* a code. That is, the order of the bases (letters) makes one gene different from another gene (just as one page of print differs from another)” (Judson, 153). At this point, Crick is only referring to the base sequence, comprised of A (adenine), C (cytosine), G (guanine) and T (thymine). These abbreviations are tropes, transporting the bases into the realm of language. The capital letters are characters in a new language: through their different combinations and relation to each other, like letters spelling words, fundamental units in a language, the base “letters” spell

proteins, fundamental units of biology. These base letters are letters in a biological alphabet, and important for conveying information. G always signifies guanine, just as the written letter “g” is constant. It is the relation of G to A, C, and T that create different meanings, just as the letters gt, ga, and gc form combinations with different meanings. The bases themselves are not information; however, *combinations* of bases, like combinations of letters, *are* information.

The metaphor of DNA as language pervades textbook and newspaper explanations. The subsequent discoveries of how the genetic code operates solidified this trope of DNA as language. The codons, or three-base sequences that specify amino acids, are described as words, and “codons that specify the same amino acid are termed synonyms” (Voet, 900). Each codon-word is made of the smallest possible units, the bases adenine, guanine, cytosine, and thymine. By understanding the bases as morphemes, it becomes apparent that, in a way identical to language, the DNA “language” depends on difference. Even the slightest change alters the meaning of the sequence: just as mishearing “p” transforms “pat the cat” into “bat the cat,” mistaking T for G results, in one case, in a stop codon (TAG) which will terminate the protein chain instead of adding the amino acid glutamine (GAG).

DNA also has similarities to language in the spatial processes of reading and writing. It becomes the convention to write DNA sequences from the 5′ end to the 3′ end* (Voet, 899), standardizing the method of using genetic code in the

same left-to-right direction as written language in Latin- and Greek-based alphabets. This produces hierarchies of the information contained in the sequence according to language, because the 5'-3' strand is termed the "sense" strand, whereas the 3'-5' strand is the "antisense" or "nonsense" strand. In replication, reproducing the nonsense strand is more complex than the steps in transcribing the sense strand, because the nonsense strand must be copied in fragments and then sutured. The 5'-3' or sense strand duplicates linearly, in a process analogous to reading and transcribing text in Western languages. The familiarity of this process makes it seem simpler than the replication of the nonsense strand and motivates the convention. Therefore, even though the strands are mirror-images of each other, the sense strand is privileged (evident even from the nomenclature) because it is easier to "read."

The arrangement of the code and how it is divided into units is also conceptualized according to the conventions of written language. The code is defined in term of punctuation: UAA, UAG, and UGA⁴ are known as "stop" codons, analogous to periods of sentences. In *Essential Biochemistry and Molecular Biology*, a typical textbook, the code is described as "commaless" (155) because "one triplet on the mRNA is directly followed by the next one without any additional signal between them, and [not] overlapping" (155). The analogy of the genetic code as language is limited, however: we can speak of the code as

⁴ DNA is composed of bases G, C, T, and A, but new DNA is copied from an mRNA (messenger RNA) template. RNA is composed of bases G, C, T, and U (uracil). The genetic code is written for the mRNA template, with U replacing T.

commaless but to assert that there is a “grammar” is to make the analogy too complexly tied to language and its rules. Similarly, Voet states, “the elucidation of the genetic code dictionary therefore proved to be a difficult task” (897).

Though the genetic code is analogous to a lexicon, it is a finite one and resembles a table more than a dictionary. In addition, there is none of the ambiguity that is present in language, in the aspect of multiple meanings: the words “frock,” “gown,” “jumper” all represent one type of garment; conversely, all those specific types of garment can be called by the name “dress.” The degeneracy of the genetic code, however, only operates in one direction—that is, there are 64 codons and 20 amino acids, so some amino acids have more than one codon; but there are not codons that represent more than one amino acid in the way that the word “dress” can signify many slightly different types of garment.

Crick, discussing how to use the genetic code, explains in terms of language: “if you are given one set of letters you can write down the others” (Judson, 153). Here he refers to the predictable base pairing nature of double-stranded DNA. This is the fully realized implication of Chargaff’s ratios, and is referred to in the paper: “If only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.” This aspect of DNA structure is the foundation of the copying mechanism. The process of transcription makes a reversed copy; the strand is traced to produce a copy of its opposite. This undergoes translation, where the nucleic material codes for protein, each codon

of three bases indicating an amino acid until a sequence is produced and a chain is completed. These proteins are the translated trace of the genetic material. They are the basic forms from which molecules are produced and biological processes are maintained in the body. Yet the trace of the genome is, in Derridean terms, “always already” present, and all the way upwards through the emergent chain of biology that begins with amino acids and ends with an organism. It is a writing that writes and re-writes itself, it is written by no one and read by no one. This unconscious biological writing has no author, and an authorless writing asserts a lack of metaphysical presence, a lack of original DNA, of a definite beginning or an initial palimpsest plate, as well as no definite end, no goal, no teleological purpose. In this sense of ambiguous origin and end, DNA is like a natural language (de Saussure, *Course in General Linguistics*).

Yet it is immensely relevant that the most fundamental of biological processes is comprehended by a turn of thought involving language, because language has become a focal point of academic activity with the relatively recent acknowledgment that it is central to all that we do. To link language and biology, then, becomes an overlap in the traditionally separated areas of arts and science, a way of considering the language of biological science and the metaphors used in the discipline.

Crick mentions that Watson and he did not invent the structure, it was waiting to be discovered. This acknowledges that the molecule existed before their model, but also assumes that their model accurately represents the real

molecule. It would perhaps be more accurate to think of Watson and Crick's work as mapping, charting, the DNA molecule rather than providing an exact replica. As a language, DNA provides a way of organizing reality, the reality of biology, as language maps reality. Language provides a system for understanding reality by giving names to physical things, emotions, and actions. In the process of naming or describing, things are differentiated but also *identifiable* in a way that is more or less equal with any speaker of that language. Language, then, implies a convention of understanding. However, language is descriptive and representative: it is not equal to reality but is a system for understanding, organizing, and perceiving reality. Similarly, the DNA model is a way of representing and perceiving a subcellular structure, but, like language, the conventions (i.e., diagrams) used to describe the structure are not equal to the structure but are instead systems for understanding and representing that structure. The molecular structure is displayed by displacing it from the physical world into figuration.

Yet it is ironic that we are trapped in the trope of thinking of DNA as a biological language. It is chiefly our acceptance of the physical structure that illustrates and maintains our concept of DNA. Bonnie Spanier calls attention to our method of understanding by analogy and objects to popular tropes of DNA. She finds that the idea of DNA as the controller of the cell reinforces hierarchies that are already problematic in other areas of human experience. Her careful reading of these tropes also usefully calls attention to the use of metaphor in

science and the difficulty that scientists discover in trying to explain new phenomena.

Language is necessarily discursive; in the same way, DNA, as biological language, provides an inscribed understanding of the processes of creation that hold metaphysical mystery; it is, by analogy, the model of something as fundamental in biology as language is to consciousness. And, as with language, which we cannot step outside of to analyze, so we cannot escape the inscription of DNA. At most we can decipher these codes and unravel our biology.

Any explanation, regardless of how scientific, must be relayed through language; a scientific explanation must necessarily also enter the field of scientific discourse--it is an addition to a debate, perhaps, or at least to existing knowledge. "A Structure for Deoxyribose Nucleic Acid" enters the scientific discourse on nucleic acids, both responding to previous research and contributing knowledge and an argument that will in turn be responded to. The paper itself is discourse. Hayden White, in *The Tropics of Discourse*, examines the process by which discourse is produced, arguing that new knowledge or information necessarily must be mediated by language and therefore will be constituted by tropes. Any attempt to delineate new ideas must proceed by a method similar to analogy but capable of not simply equating two things: the new phenomenon must be explained in terms of what we already understand. A twist in thought, an illogical turn or swerve, must occur, to apprehend the new. For example, in trying to explain a mango, one might say that it has a smooth skin like that of a

banana, only thinner and red, yellow, or green in color; that its flesh is like a kiwi, but without the seeds, and that it tastes sweet like oranges and pineapples but with a hint of muskiness. The mango is explained by analogy with familiar fruits, but to understand it via description, via language, we must depart from what we know. Guided by modifiers, such as “thinner” or “without seeds,” a “swerve” must occur, moving away from the familiar, established knowledge and toward something new.

This turn in thought, or troping, is less logical, more metaphorical; it has more to do with creativity than with scientific method. The act of describing does not suffice; a cognitive process must result from the description for the perception to be complete. Thus troping is naturally “the shadow from which all realistic discourse tries to flee” (White, 2). Perhaps scientific discourse, with its aspirations to be completely transparent and unambiguous, is the discourse most unwilling to acknowledge turns in thought. However, it is impossible for any language to evade troping: “tropics is the process by which all discourse *constitutes* the objects which it pretends only to describe realistically and analyze objectively” (2). Troping, then is fundamental to language, and especially in descriptive language that seeks to explain a new phenomenon. Precisely because scientific discourse seeks to provide explanation for new areas of thought, it cannot simply describe in the terms already available; it relies on a recombination, a re-synthesis, a re-comprehending, based on existing knowledge but at the same time incorporating new information.

This centrality of discourse in apprehending and organizing knowledge is common to all disciplines and the method is archetypal. Though Hayden White only considers the social sciences, it is plausible to expand this range and look at the discourse of other disciplines, in this case natural science, to investigate the reliance of the discipline on discourse, and in turn, the inevitable reliance of the discourse on tropes.

White states that there is an “archetypal plot of discursive formation,” a repetitive pattern. He explains: “discourse...serves as a model of the metalogical operations by which consciousness...effects such comings to terms with its milieu, social or natural as the case may be” (5). Thus, discourse is not merely a product of consciousness but is analogous to the way we acquire any new knowledge. This stems from the impulse to organize a way of thinking about our environment in general. As the philosopher of science Alfred North Whitehead observes, “science started with the organization of everyday experience” (*Science and the Modern World*, 144). White considers that discourse is central to that organization: “[the] diataxis of discourse not only mirrored the processes of consciousness *but in fact underlay and informed all efforts of human beings to endow their world with meaning*” (5, emphasis added).

White also determines a pattern in tropological activity, and concludes, examining Piaget, that the “master tropes [metaphor, metonymy, irony, synecdoche]...are grounded...in the psychogenetic endowment of the child” (12).

Therefore, the mechanisms of troping are cognitive and universal, activities that are fundamental to perception and cognition.

All language upon utterance (whether verbal or written) enters discourse. Discourse is the process of exchange, the interactions and contexts of these utterances: each utterance enters a certain historical and cultural context, and both responds to and initiates the possibility of being responded to. Discourse can be as simple as a telephone conversation, with each utterance being, more or less, a sentence. It can also refer to a specific discourse, such as scientific discourse, which includes papers, conferences, and specialized communications between scientists on specific topics. Discourse, however, is not merely a generative exercise but also a

mediative enterprise...it is both interpretive and preinterpretive; it is always as much about the nature of interpretation itself as it is about the subject matter which is the manifest occasion of its own elaboration...every discourse is always as much about discourse itself as it is about the objects that make up its subject matter. (4)

Thus White's definition of discourse necessarily shuns any illusion of transparency and establishes another level of looking at texts. In a scientific paper such as "A Structure for Deoxyribose Nucleic Acid," the discursive elements are important. White argues that "the tropological theory of discourse gives us understanding of the existential continuity between error and truth, ignorance and understanding, or, to put it another way, ignorance and thought"

(21). To this list of polar opposites that discourse mediates between, let us add science and art.

White proposes analyzing discourse on three levels: mimesis (data), diagesis (argument or narrative), and diataxis (the synthesis of mimesis and diagesis) (4-5). In looking at "A Structure" and considering the continuities of science and art, the importance of the diagram of DNA emerges. This diagram, a component of discourse, evokes the continuity of representation and reality--not polar opposites, but not synonymous. The simple model is the culmination of the data, the diataxis or synthesis of the paper and the claims it makes--the model represents the basic skeleton structure and implies the possibilities of base pairing and replication. Into this model fit all the claims that Watson and Crick make, in addition to their assumptions. The model has a curious function of both synthesizing the data and representing the data in one visual trope. In this way, the model itself is discourse, text, and can be analyzed as such. Yet in attempting to represent reality, or the reality of the structure of the DNA molecule, the diagram overlaps the realm of art: like architecture, painting, poetry, it performs an act of mimesis. White cautions,

[with] texts intended to represent 'things as they are...' there is always a failure of intention. Every mimetic text can be shown to have left something out of the description of its object or put something into it that is inessential to what *some* reader, with more or less authority, will regard as an adequate description. On

analysis, every mimesis can be shown to be distorted and can serve, therefore, as an occasion for yet another description of the same phenomenon, claiming to be more realistic, more 'faithful to the facts.' (3)

This gap in "logical consistency" is of course also found in visual discourse and introduces the importance of attentive interpretation.

White states at the beginning of his introduction that "the coherency of the data always resist the image which we are trying to fashion out of them" (1). Just as linear graphs are "best-fit" lines, averages of data, rather than a series of accurate, measured points, so is all data resolved into averaged representation. The data is information *about* something; the diagram, graph, or model is the generalization, the conceptualization, the theoretical image that can be proposed from the data.

This discrepancy between data and image is also noted by Charles Bazerman, who analyzes academic discourse from the three areas of the natural sciences, the social sciences, and the humanities in his 1981 paper, "What Written Knowledge Does: Three Examples of Academic Discourse." He reiterates that "language is not an inert vessel" (361) and emphasizes that "to understand what language conveys we must look to the contexts in which language operates" (361). What he finds of importance in scientific discourse is that there must be a closeness of fit between data and claim, similar to White's relationship between data and image. In the case of "A Structure," this argument is particularly

appropriate. Bazerman states: "the claim of representing an actual structure rather than creating an approximate model results in a strong requirement between data and claim" (366). Though the figure included in the Watson-Crick paper is "purely diagrammatic" (their words suggesting an offhand sketch), the claim of the paper, however, is to elaborate definitively a structure for DNA. The model is a persuasive element, a design that embodies all of the major features of the structure, whereas the written section of the paper elaborates on this intermediate element, giving precise details of measurement. Together, both diagram and written language form the text of the paper. The diagram serves as a simple map, a blueprint, onto which the reader then may apply the more mathematical details. But the diagram as intermediate also marks a transition, making the claim for the actual structure easier and also more authoritative because the imagination is channeled into thinking of that structure as the diagram represents it.

However, in attempting to represent there is first an assumption that the molecule exists as a physical entity. While a poem may try to represent something that has no identifiable physical existence, such as sorrow, in science the underlying assumption is that a structure similar to the one proposed does exist as an entity in the world. Furthermore, where DNA is concerned, this molecule is presumed to predate the discovery of its structure. The difference between invention and discovery is important. Watson and Crick did not discover something concrete and immediately observable, like a new metal or a

new species. Instead they discovered an approximation of something that is presumed to exist. Perhaps more accurately, they mapped the DNA molecule.

Yet the assumption of the pre-existence of the DNA molecule gives it a status in the drama of its discovery. It is like an elusive and silent player in a game, a plot, a narrative. Crick personifies the molecule: “rather than believe that Watson and Crick made the DNA structure, I would rather stress that the structure made Watson and Crick” (768). In Watson’s more subjective view in *The Double Helix*, it is the molecule that is the focus of the title, and, indeed, the subject of the book. This, combined with the autobiographical tone, results in a curious hybrid—a book that is a biography of DNA as much as it is a scientific autobiography of Watson. In this way the molecule figures as an unusual character in a narrative.

Judson also presents the events leading up to the elucidation of the structure as fiction, but in terms of the trope of theatre. He provides lists of “the chief persons of the comedy” according to their locations: “in Cambridge, at the Cavendish Laboratory; In London, at King’s College; In Pasadena, at the California Institute of Technology...” (8-9). Of each character a brief description is given, including professional skills and interests and personality traits. For example, his descriptions of Watson and Crick:

Francis Crick, English physicist turned to biology after the war’s interruption; in his mid-thirties still a Ph.D. candidate; a mind

effervescent, stimulating, dry, unmistakable--and at this time not yet matured.

James *Watson*, American biologist on a postdoctoral fellowship, eleven years junior to *Crick*; a young man who had decided that science, whatever else, was the main chance; the unequivocal hero who has since cast himself as maybe the villain. (8)

The comedy is also complete with “informants and messengers” (8), such as Peter Pauling and John Griffith. DNA itself is not listed as a white rabbit character, yet it is no less part of the narrative. In a sense, it is a desired object, like the treasure in a fairy tale, presumed to exist in much the same way as the other players exist though less easily representable.

Judson states: “DNA is an outstanding example of how a discovery twists and grows. What is still called the Watson-Crick structure of DNA is different today in factual detail from their first short paper in *Nature*, and very much greater in perceived scientific consequences” (9). Accordingly, the representations have also become more complex. Compare the original DNA diagram to that provided in Voet and Voet’s *Biochemistry*:

(see next two pages)

The molecule itself becomes the principal subject of a narrative of accuracy.

Once the basic structure was found, details could be investigated, measurements

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MOLECULAR STRUCTURE OF NUCLEIC ACIDS

Structure for Deoxyribose Nucleic Acid

WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable logical interest.

A structure for nucleic acid has already been proposed by Pauling and Corey¹. They kindly made their manuscript available to us in advance of publication. Their model consists of three interwoven chains, with the phosphates near the fibres, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons:

(1) We believe that the material which gives the ray diagrams is the salt, not the free acid. Without acidic hydrogen atoms it is not clear what forces could hold the structure together, especially as the actively charged phosphates near the axis will elude each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate diester groups joining β -D-deoxy-ribofuranose residues with 3',5' linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furbert's² model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furbert's 'standard configuration', the sugar being roughly perpendicular to the attached base. There

Figure is purely schematic. The two lines symbolize the phosphate-sugar units, and the horizontal rods the pairs of atoms holding the chains together. The vertical marks the fibre axis.

is a residue on each chain every 3-4 Å. in the z-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, after 34 Å. The distance of a phosphorus from the fibre axis is 10 Å. As the phosphates are on the outside, cations have easy access to them.

The structure is an open one, and its water content is rather high. At lower water contents we expect the bases to tilt so that the structure becomes more compact.

The novel feature of the structure is the manner in which the two chains are held together by purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are together in pairs, a single base from one chain hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical co-ordinates. One of the pair must be a purine, the other a pyrimidine for bonding to occur. Hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in one structure in the most plausible tautomeric form (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: a purine with thymine (pyrimidine), and a purine with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly, guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases are formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally^{3,4} that the amounts of adenine to thymine, and of guanine to cytosine, are always very close to 1:1 for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose; the extra oxygen atom would make too close the van der Waals contact.

The previously published X-ray data^{4,5} on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and chemical arguments.

It has not escaped our notice that the base pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

Full details of the structure, including the conditions assumed in building it, together with the co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on atomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. Wilkins, Dr. R. E. Franklin and their co-workers.

Figure 28-5

The structure of B-DNA as represented by ball-and-stick drawings and the corresponding computer-generated space-filling models. The repeating helix is based on the X-ray structure of the self-complementary dodecamer d(CGCGAATTCGCG) determined by Richard Dickerson and Horace Drew. (a) View perpendicular to the helix axis. In the drawing, the sugar-phosphate backbones, which wind about the periphery of the molecule, are blue, and the bases, which occupy its core, are red. In the space-filling

model, C, N, O, and P atoms are white, blue, red, and green, respectively. H atoms have been omitted for clarity in both drawings. Note that the two sugar-phosphate chains run in opposite directions. (b) (opposite) View along the helix axis. In the drawing, the ribose ring O atoms are red and the nearest base pair is white. Note that the helix axis passes through the base pairs so that the helix has a solid core. [Drawings copyrighted © by Irving Geis. Computer graphics courtesy of Robert Stodola, Fox Chase Cancer Center.]

honed. Precision prevails, yet the structure is by no means an exact representation even now. There will always remain a gap between the real, physical structure and the ability to apprehend and represent it. The searching precision, however, indicates a teleological belief that each more mathematically precise structure is closer to the real physical entity, is more authentic or truthful, more correct—because it has more of the essence, apparently, of the elusive ideal.

Bazerman differentiates: “geometry as a study is the product of human consciousness, but geometric forms are claimed to preexist human invention” (366). This is analogous to the way that the object is presumed to exist and is not invented or brought into being by human understanding; but human understanding organizes, generalizes, and decides how to best represent the object.

Correspondences between perception and structure in science determine the type of authority the figures contain. In the Watson-Crick paper, Bazerman finds:

...the fourth through eighth paragraphs cast the geometry into words, add details, and clarify elements of the structure through reference to accepted causal statements, prior work, and other models. The five paragraphs are descriptive, recreating physical presence through the symbolic systems of words and numbers, but the symbols are more than approximate metaphors. The names point to discrete objects, and the geometry is of nature itself.

Scientific language, as a symbolic system with a commitment to reform itself in accordance with replicable observation of nature , becomes more than an arbitrary symbolic system. (368, emphasis added)

That is, science claims a relation to nature that has authority and can be proven by mathematics and empirical knowledge. However, what we must recognize is that the representation of this nature is always necessarily flawed and never a perfect mimesis. Yet the claim to represent nature gives scientific diagrams authority. These structures, nevertheless, remain representations, models, metaphors, however close the correspondence. The similar models are tropes that have an arbitrary authority bestowed on them by the closeness of fit of the model to the data. It is the method of observation that determines this closeness and the effectiveness of the metaphors. These observations are closely intertwined with other cultural practices and hierarchies, and just as the mimetic aspect of scientific discourse must be examined as a method of persuasion, so must the visual mimesis of scientific diagrams and models.

IV

What then, is the importance of these visual metaphors that occur not only in “A Structure for Deoxyribose Nucleic Acid” but are part of the persuasion of nearly every scientific paper, and with growing frequency? If we think of two narratives of DNA, we discover that the discovery of the structure corresponds with the arbitrary closure of the narrative. Watson’s book, *The Double Helix*, ends with the discovery, implying a definitive end to the quest. The paper also implies a closure to the problem, to the narrative begun in models proposed by Frasier, Fruberg, and Pauling/Corey. This assumption that the structure is a solution or answer to a problem implies a step “forward” and that another quantum level of knowledge has been attained. This belief in answers and progress is a teleological staircase that many, if not most, scientists seem to have a sense of abstractly climbing.

Yet there are examples in science that show radical changes in the models that were once so definitive. The Ptolemaic universe was exchanged for the Copernican model; the models of the atom proposed by Bohr and Rutherford have been replaced (Tibbetts, 79); B-form DNA, or Watson-Crick DNA, does not closely resemble the structure proposed in 1953. What progress can be thought of in this context? Certainly the models of DNA have become more specific, and more differentiated, with the discoveries of other helices, such as Z-form DNA. Even concentrating on models of Watson-Crick DNA, the specificity of these models has increased: they are more detailed and accurate due to results of experimentation and to better techniques used to create representations, and they are often more visually complex, implying a greater knowledge of the molecule in general.

The use of models in twentieth century chemistry and biochemistry, largely initiated by Linus Pauling, has proved influential. Pauling often used folded paper and other materials to help him work out structures, such as the alpha helix (Goertzel, 88). First, he improvised with materials to represent atoms and bonds; later, he had standardized model pieces built. This allowed him to build structures that would, theoretically, have correct bond lengths and numbers of atoms. These models are widely used now, and nearly all introductory university organic chemistry classes require students to buy a simple kit with which to build plastic molecules. Textbooks also feature three-dimensional drawings and come equipped with appropriate viewers.

Having models that are produced to a specific size, a specific ratio to the known measurements of atoms, bond lengths, and angles introduces a tactile and visual aspect that, for example, x-ray photographs lack. In the case of the structure of DNA, Watson and Crick consciously adopted Pauling's model-building technique. Crick also remarks that "the proposed duplication mechanism was spelt out in simple terms, unmarred by any trace of algebra" (767). Nevertheless, Rosalind Franklin was also close to analyzing the structure by the method of x-ray crystallography, and this method was used successfully by Max Perutz to elucidate the incredibly complex structure of hemoglobin. It is difficult to privilege one method over the other, except in the context of individual preferences⁵. Models, photographs, diagrams: all can be thought of as types of maps. They display the obvious and repeatable features of a physical phenomenon, in a form of reduced complexity that makes the physical form easier to imagine and understand.

Despite the reduced complexity of the form, an additional component, spatiality, is introduced by models. Models show in three dimensions the arrangement of atoms in space. Edward Soja, in *Postmodern Geographies*, writes an important reminder:

The root of semiotic and semiology is the Greek *semeion*, which means sign, mark, spot, or *point in space*. You arrange to meet

⁵ However, Crick suggests that, while Franklin and her assistant Gosling contributed many good ideas about the structure, they missed the base pairing because "they had done no proper model building" (*The double helix: a personal view*, 766).

someone at a *semeion*, a particular place. The significance of this connection between semiotics and spatiality is too often forgotten.

(246n)

Each ball is a sign for not only an atom but an atom in space. The straight sticks are signs for bonds, and in a model the unoccupied space is also apparent and easily observed as part of the geography of the molecule. This is an advantage in perception over x-ray crystallography, which relies on two dimensions, and sometimes many structures can fit the photographic evidence. With models, complex organic molecules that are difficult to represent in two dimensions can be manipulated in space, using models that correspond by ratio to bond lengths and atom sizes.

Yet by having models and diagrams that represent specific ratios of representation to known measurements, a transfer of authority occurs. The model, rather than representing nature, suddenly has, through presumed accuracy, the power to become nature. Prelli emphasizes this:

The model was a proposal about the physical world, and had not yet been confirmed through empirical investigation. Nonetheless, what the proposed model claimed to do was represent an actual empirical structure. Its success would depend ultimately on the ability to induce ontological commitments--the belief that DNA's molecular structure is not *like* a double helix but *is* a double helix.

(243)

This type of ontological claim, resulting from such a simple model and an even more simple diagram included in the paper, seems alarming and an overextension of the metaphor of the structure of DNA. But in considering Prelli's position, both parts of the phrase are true: DNA *is*, topologically, a double helix, perhaps not exactly the double helix as described by the original model or the diagram in the paper, but a double helix that is at least *like* these two representations. So the molecule itself, then, both is and is like a double helix, because the structure is a double helix, but not one that we can directly perceive. Therefore, DNA is like a double helix in the sense that we must always think of it through representation. The math and the metaphor merge.

Lynch considers models in a similar manner:

Models enable certain theoretical relations to be represented as though they were 'in' the depicted objects. Models use visual conventions to denote change, sequence, activity, and relationships of various kinds. The object becomes more *vivid*; we can picture it as though it were 'naturally' present for our inspection.

Mathematization includes practices for assembling graphic displays. Specimen materials are 'shaped' in terms of the geometric parameters of the graph, so that mathematical analysis and natural phenomena do not so much *correspond* as do they *merge* indistinguishably on the ground of literary representation. (181)

Yet Lynch warns against the “attribution of mathematical order to nature” (182). This common practice, aligned with teleological belief, facilitates the transfer of authority into models and diagrams. In scientific papers, figures show what the text proves (Lemke, 108); in “A Structure,” geometry and representation are combined in the simple diagram. Jay Lemke calls these text-plus-figures papers “semiotic hybrids,” (87) and they have acquired an unprecedented authority because of the relationship with mathematics. As a result, these figures become the transparent language that Thomas Sprat privileges over adorned rhetoric in his prescription for scientific language in *The History of the Royal Society*. Additionally, the use of figures becomes more prominent in an era where language is being questioned, when the persuasive elements of scientific language are being recognized and analyzed, and the subjectivity of scientific method is being acknowledged.

It is perhaps also true that figures are used more frequently because they are now easier to produce, and the ability to create new kinds of images is continually becoming more widely available with the rapid advances in computer technology. However, it is also true that, if representation can become more sophisticated, then mathematics can also. In this vein we may think of models and diagrams as becoming *more complex* but not necessarily converging upon a *more correct* answer. The map that Watson and Crick try to create is of a subcellular unit, a part of a nucleus; a large molecule, but a molecule nonetheless, and one that we are unable to observe in any detail. In comparing the mapping

of the DNA molecule with the mapping of, for example, Chile, we discover two visually insurmountable objects. Insurmountable in both cases because of scale: in the first instance the object is too small (or the eye too undiscerning); in the second, the eye too small, or the country too large. Both of these terrains encompass a great deal of space that is unseeable--unlike, for example, a room in a house. A map of Chile can be simple, like the diagram of DNA, illustrating how an outline is immediately recognizable because it features repeatable phenomena about the shape of Chile. Maps can be more complex, showing relief, land value, population, concentration of wealth, weather; theoretically, one could attempt to provide a map of all the atoms in Chile in the same way that some DNA models try to account for each atom. Maps of Chile can be said to be improved or made more accurate; for example, one road map of Chile may include more roads, or show the distances more clearly than another. In the same way, DNA can be mapped for its atoms, its helical pitch, its charge and size and sequence. Yet the map is always partly a representation, an interpretation, a momentary narrative of some feature of the terrain. In the same way that there is no absolutely true textual narrative of the DNA discovery, whether it is Watson's, Crick's, Chargaff's, Rosalind Franklin's, or Linus Pauling's account, there will be no definitive maps of DNA. Historiography maps historical events; diagrams and models are maps of biological and scientific phenomena.

Like language, like narratives, then, the difficulty lies in how we know what we do about the subject. As with language, we gain knowledge only

through difference (de Saussure, 123), and this is true of models as well. Lynch and Woolgar address this in the introduction to *Representation In Scientific*

Method: “our posit is that representations and objects are inextricably interconnected; that objects can only be ‘known’ through representation.

Criticism necessarily involves competition between representations, not between a representation and an ‘actual object’”(13).

Paul Tibbetts also argues against the realist idea that

the reason why at least some RDs [representational diagrams] (e.g. the three-dimensional DNA model of Watson, Crick) function as such powerful predictive and explanatory tools in science is simply because such models more and more come to approximate reality through successive model revisions. (79)

Instead, Tibbetts prefers to do away with this debate and consider the value of models and diagrams without “mapping in any truth-preserving fashion onto anything at all” (79). This removal of the ideal of an ‘actual object’ leaves only representations in relation to each other instead of mimicking an “actual reality” that exists independently and outside of our ability to comprehend and represent. Thus, Tibbetts’ argument suggests that the representations themselves are the reality. He quotes aptly from Hacking:

With the growth of knowledge we may, from revolution to revolution, come to inhabit different worlds. New theories are new

representations. They represent in different ways *and so there are new kinds of reality*. (81, emphasis added)

This idea of new representations being new realities links to Kuhn's ideas of scientific revolution and paradigm shift. Kuhn states:

Paradigm changes do cause scientists to see the world of their research-engagement differently. In so far as their only recourse to that world is through what they see and do, we may want to say that after a revolution scientists are responding to a different world. (111)

Importantly, in order to have these shifts, in order to exchange one representation for another, the role of the representation relates to the role of the observer. The Modernist realization of multiple viewpoints, chiefly evident in the Cubism of Picasso and Braque, is the precursor to the postmodern concern that the gaze of the observer is not neutral, but always embodies subjectivity. This figures in interpretation and, rather than simply being a negative and endless series of possibilities, is realized positively by critics such as Sartre ("Why Write?") and Eco ("The Role of the Reader") who believe that the reader, in the act of reading, essentially completes the text.

Similarly, the observer is crucial to visual representation. Bazerman elaborates on this relationship:

The manipulation of symbols within generic disciplinary space to unfold meaning is also a *cognitive activity, drawing together the*

understandings and interests of the writer and readers in joint projects, so that readers must be engaged, influenced, and persuaded by the unfolding text...the joint construction of meaning is more than simply a calculus of symbols, it is a rhetorical sharing of thought within a generically identifiable space... (27, emphasis added)

This neatly explains how Lemke's "semiotic hybrids" are produced: the paper proposing the structure of DNA is specifically technical, intended for experts on the structures of biological molecules and simultaneously rhetorical, making an argument or claim through steps of logic and language. Because of this rhetorical aspect, even the most straightforward of scientific contexts necessarily involves persuasion.

Inside the specific contexts, persuasion is constructed through diagrams and models by orienting the writer and reader to a common reference point or point of observation. This is what Latour refers to as "optical consistency" (*Representation in Scientific Practice*, 27). Though he speaks of painting, his comments are also true of representations in science: "...on paper, hybrids can be created that mix drawings from many sources. Perspective is... interesting because it creates complete hybrids: nature seen as fiction, and fiction seen as nature..." (29). In the case of the double helix, the molecular diagram is fiction, a metaphor for DNA, and at the same time exacts an authoritative status as 'nature,' recalling Prelli's observation that the proposal is not that DNA is *like* a helix but that it *is* a helix. In this way Latour finds the reduction that

representation inevitably involves to be connected with issues of power, because the representations are not synonymous with reality. He states that though “inscriptions are immensely less than the things from which they are extracted, it is still possible to dominate all things and all people. What is insignificant for all other cultures becomes the most significant, the only significant aspect of reality” (60).

The figure included in “A Structure for Deoxyribose Nucleic Acid” is, certainly, a model reduced in complexity in order to persuade the reader of a specific shape for the molecule. This visual image has been remarkably influential and is readily recognized outside of scientific milieux. It is important simply as an example of the use of models and figures in scientific discourse; but it also has status conveyed by the impact of the ideas it represents. Kuhn speaks of consensual seeing through shared paradigms: though he uses “seeing” in a figurative sense, the DNA helix is a visual trope that represents the ideas of a scientific revolution.

The diagram is representative of a new language in science, a language that has a transparent authority. As representation, figures are thought to represent nature itself, or an independent reality. This authority must be questioned; just as written language cannot achieve the “plainness” that Sprat desired, neither can other systems of representation.

In order to bestow authority, however, an observer must be involved. In this respect, scientific figures rely on creating a convincing “optical consistency,”

a persuasive structuring of the observer's perspective in relation to the data. In the case of the DNA helix, the representation is the visual trope of a paradigm shift in science and in culture and general knowledge. It is an emblem of a new consensual view of biology; the sublime elegance of the curving strands embodies all of the implications of base pairing and the ability to write and rewrite a biological writing. This secularization of biology removes divine mystery, but it seems that it also has conferred unusual power on the scientist. Judson acknowledges this in calling his book *The Eighth Day of Creation*; but the status of the scientist in less contextually expert environments is demonstrated by Salvador Dali's remark: "and now the announcement of Watson and Crick about DNA. This is for me the real proof of the existence of God" (quoted in Stent, 779). Though Dali does not confer the power of creation on science, his comment does confer an interesting rhetorical authority: perhaps Watson and Crick are not equal to, or a new version of God, but, for Dali, they can *prove* God.

V

Paul Tibbetts, in “Representation and the realist-constructivist controversy,” argues against the idea that proximity to reality constitutes the value of a diagram or model, citing models that, despite seeming to constitute an understanding of a part of reality, have been shown to be incorrect and have been abandoned in the methods of thinking about that particular concept. Tibbetts separates the necessity of representing truth from the value of the diagram. He writes: “an RD can therefore possess heuristic value without necessarily mapping in any truth-preserving fashion onto anything at all. That is, the RD need not preserve or capture anything about a so-called mind- and culture-independent reality” (*Representation in Scientific Practice*, 79). He continues, raising the question, “why do some RDs have more heuristic value than others?” (79). Tibbetts does not respond except to acknowledge that the answer is more complicated than simply an evaluation of how well an RD represents reality. It is this particular question of why some RDs have more

value that should be addressed in the case of the DNA diagram included in the Watson-Crick paper.

The structure of DNA is a well-recognized concept because of a number of circumstances, as this paper and other work has discussed. The historical moment of its unveiling was one of anticipation rather than resistance to a new and unnecessary idea; instead, momentum was building. The rhetoric of the paper also contributes to the rapidity of acceptance; the written text alone has been much analyzed as a successful argument, due to its arrangement, logic, and brevity. Yet the diagram is an overlooked part of this rhetoric, despite its deliberate inclusion in the text of the paper, and the proportion of valuable space it commands, and that it becomes more memorable than the written parts of the paper. This diagram becomes a familiar outline associated with DNA; this diagram, or ones similar to it, are reproduced to represent DNA in many contexts, scientific and popular. The diagram is pervasive in all texts discussing DNA, from scientific discourse to popular culture. The double helix is a widely recognized image, and it is precisely its pervasiveness that demands investigation.

A return to Bruno Latour's ideas of "optical consistency" illuminates a particular spatial relationship between the reader, the author, and the data. Latour reminds us that, in using a diagram, "you present absent things" (27). The diagram is necessarily a representation; furthermore, it is a two-dimensional representation. This two-dimensionality is also a control over perspective. The author and reader perceive the data by looking "through the same

‘windowpane’ on the same two-dimensional surface” (28). Thus the diagram is a component of the rhetoric of the paper because it is data organized by the author into a persuasive arrangement. The use of diagrams also has a visual immediacy that is nonlinear: in absorbing the diagram, there is a difference between “reading” and “looking.” The reader of the paper stops the linear process of *reading* left to right down the page and instead *looks* at the diagram with a less structured pattern of eye movement. This visual arrangement also ensures that both the author and the reader perceive the data with the same spatial orientation, much as if they were looking at a painting from the same viewpoint. Importantly, this ensures that, at the same time that one point of view is apparent, others are occluded.

The importance of shapes and orientation of perception is illuminated by George Lakoff and Mark Johnson in *Philosophy in the Flesh*, a re-examination of philosophy through cognitive science. They conclude that reason is not a separate, discrete faculty but that it is an extension of the body. They state:

Reason is not disembodied, as the tradition has largely held, but arises from the nature of our brains, bodies, and bodily experience. This is not just the innocuous and obvious claim that we need a body to reason; rather, it is the striking claim that the very structure of reason itself comes from the details of our embodiment. The same neural and cognitive mechanisms that allow us to perceive and move around also create our conceptual systems and modes of reason. (4)

This links reason to the body, and, significantly, acknowledges that the experience and functions of the body participate in reason. Therefore, reason cannot be objective or involve only conscious thought.

Conscious thought is shaped by unconscious thought, and unconscious thought “is 95 percent of all thought” (13). The unconscious “shapes how we automatically and unconsciously comprehend what we experience” (13). Much of our knowledge is included in the unconscious⁶, as well as how we use it to infer new knowledge. These processes are nonlinear and linked to experience, including physical, embodied experience. Therefore, reason cannot be separated entirely from bodily experience; indeed, Lakoff and Johnson insist that: “there is no such fully autonomous faculty of reason separate from and independent of bodily capacities such as perception and movement” (17). Reason relates to both the body and to the surrounding world, but in neither a completely subjective nor objective way.

The faculties of perception are related biologically to those of conception: the same neural system is responsible for both (38). More specifically, in order to generate knowledge, experience must be a factor. In particular, concepts about spatial relations arise from the body’s experience of spatial relations. We are equipped with cells that sense and monitor our orientation in space; we can also perceive depth visually. Therefore, as Lakoff and Johnson state, “since spatial-concepts are about space, it should not be surprising if our capacities for vision

⁶ “Unconscious” here is not equivalent to the Freudian unconscious, the realm of repressed desire. It refers to the imperceptable processes of the brain in relation to the rest of the body.

and negotiating space are used in constituting spatial-relations concepts and their logics" (39). Importantly, the logic of the concepts is organized by experience rather than abstraction.

Literal experience such as moving through the world is undeniable and forms basic and nonmetaphorical knowledge. From this, metaphor and abstraction arise and form a large proportion of our thought. The first part of this relates to literal experience: "reason is embodied in that our fundamental forms of inference arise from sensorimotor and other body based forms of inference" (77). The second part is using this information for the process of abstraction: "reason is imaginative in that bodily inference forms are mapped onto abstract modes of inference by metaphor" (77). Thus even metaphor has a relation to the world through the basic experience of that environment.

This basic knowledge allows us to participate in understanding the world according to certain systems. For example, scientific thought seeks to use reason and abstraction to explain observable phenomena. Lakoff and Johnson acknowledge that "science is a social, cultural, and historical practice, knowledge is always situated, and what counts as knowledge may depend on matters of power and influence" (89). Yet they also reject pure subjectivity, accepting that "there is a world independent of our understanding of it...[and] we can have stable knowledge of it" (90). Stable knowledge consists of "basic-level concepts--characterized in terms of gestalt perception, mental imagery, and motor interaction" (90). From these basic level concepts, we can produce hypotheses, inferences, and make predictions. However, because these concepts

arise from the body, they cannot be absolute. “Metaphoric language is a reflection of metaphoric thought” (122-3), but these metaphors have a relation to the physical world and relation to a concrete truth that stabilizes knowledge from the uncertainty of complete relativity. Lakoff and Johnson assert that “we never were separated from reality in the first place” (93). Separation would imply objectivity; embodiment rejects a “strict subject-object dichotomy” (93) and instead places us in the middle ground on the continuum between total subjectivity and total objectivity.

In the case of the structure of DNA, consider a well-known photograph of Watson and Crick (next page). It shows them standing near a model of DNA, Watson looking up, and Crick pointing to the structure with a slide rule. The model acknowledges the importance of spatial relations in perception: being able to physically manipulate spatial relations between molecules was a basic-level concept that helped them to create a model of the molecule, or a complex metaphor. The pieces relate to the world, and to physical properties in chemistry; the whole is a representation of DNA, and a metaphor that arises from embodied, imaginative reason. Perception results in conception, and sophisticated methods of understanding and explaining phenomena.

However, this model is three-dimensional. Its translation into two dimensions, as the graph included in the paper, involves further metaphorizing, and a restriction in the spatial perception. In the photograph the three-dimensional structure is clearly observable, and Watson and Crick themselves have two different points of view in looking at the molecule. The diagram

removes the spatial dimension of depth, and simplifies the outline of the molecule. Its flatness ensures the same perspective for reader and author, and amongst all readers: a rhetorical continuity is achieved in what one can see, though how one looks at it is less structured than the method of reading the article.

In looking at the diagram, the eye perceives the entire shape and also begins to look, the eye following one of the curving strands, perhaps, the lines across, or the straight line up the middle. Our visual retracing of the shape corresponds to an ability to perceive it physically. Visual conventions tell us that the curved strands go around the straight middle line, but our ability to perceive this relies on our unconscious and automatic knowledge that we have experienced this in the world. We have had the experience, possibly, of holding a pole in one hand and spinning centripetally around it; more obviously, most have had the experience of going around *and* up, as on a spiral staircase. It is this tactile and sensorimotor experience of the world that allows us to perceive, from a two-dimensional diagram, the three-dimensional structure of DNA. This ability to involve the body in perceiving scientific results has an element of persuasion that is immediate and unconscious, perhaps unmediated. Our physical interaction with the model through vision is almost unconscious (we do not become aware that we are looking instead of reading). Because it evokes a familiar physical experience, it has an additional element of persuasion. Essentially, the mind is persuaded through the body.

This acknowledgement that the experience of the body shapes and influences visual perception reaches the fundamental aspect of cognition. Recognizing the importance of visual tropes requires that we understand that they are perceived in a way analogous to the experience of bodies in three-dimensional space. The experience of the body forms the bedrock of cognition; the figures, therefore, appeal to this foundation. This cognitive, physical perception of the diagram is the most fundamental method of understanding: a point of irreducibility is reached.

By understanding the role of the body in cognition we can further understand the role of visual tropes. In “A Structure for Deoxyribose Nucleic Acid,” the diagram of DNA supplements the written text effectively. The rhetorical success of the paper depends on both written and visual troping. The written rhetoric appeals to the mind through logic and evidence, whereas the diagram is a rewriting of the conclusions in a less mediated visual language that appeals directly to cognition based on the proprioceptive experience of the body. The persuasive effect of the diagram , and therefore of the paper, results in part from this sensory rhetoric. The simple double helical diagram included in “A Structure” is visual rhetoric, distilled irreducibly to the rhetoric of the body.

Glossary

Carbohydrates

Essentially, sugars and starches, common examples being simple carbohydrates:

glucose, the simplest of sugars and the one that our cells metabolize for energy;

fructose, often added to fruit drinks and in fruit, many times sweeter than sucrose.

sucrose, the sugar we are familiar with, that we put in coffee or use in cooking.

Other carbohydrates are more complex molecules, composed of many units linked together. Examples are starch and cellulose.

However, all carbohydrates are made of hydrogen, oxygen, and carbon.

Lipids

Water-insoluble molecules. The four main categories are fats, phospholipids, waxes, and steroids.

Proteins

Made of chains of 20 amino acids (see following page). The basic structure of an amino acid is a carbon with NH₂, COOH, and H attached. The fourth bond to carbon is an "R" group, which represents hydrogen, a methyl or CH₃ group, and more complex substituents.

Fibrous proteins: "provide structural integrity and strength for many types of tissue and are the main components of hair, muscle, and cartilage" (Zumdahl, 1014).

Globular proteins: "...are roughly spherical in shape...[they] transport and store oxygen and nutrients, act as catalysts for the thousands of reactions that make life possible, fight invasion by foreign objects..." (Zumdahl, 1014).

Nucleic acids

DNA (deoxyribose nucleic acid) or RNA (ribose nucleic acid), the hereditary material. The smallest units or monomers, are called nucleotides; a nucleotide is composed of three parts:

1. A *5-carbon sugar*--in RNA, a ribose sugar, in DNA, a deoxyribose sugar.
2. A *nitrogen-containing base*--one of adenine, guanine, cytosine, thymine, or uracil.
3. A *phosphate* (H_3PO_4) molecule.

Figure 23.24

A portion of a typical nucleic acid chain. Note that the backbone consists of sugar-phosphate esters.

White Blood Cells

Cells are made up of two main regions, cytoplasm and nucleus. The nucleus, surrounded by a membrane, contains the nucleic acids. The cytoplasm is everything else that is contained by the cell membrane or barrier that separates, like a skin, the cell from the world around it. This membrane, again like skin, is selectively permeable, and can admit material of use to the cell, and expel wastes. The cytoplasm is a soupy region, containing organelles and nutrients.

White blood cells, then, have large nuclei, but comparatively small cytoplasm, making the ratio of DNA to cell material higher than in other types of cells.

Acidic

Acidic, or the opposite of basic, means that the molecule, in reactions, will readily "give up" a proton, or hydrogen ion, to another molecule. A base, then, is a molecule that accepts the proton. Acids have low values on the pH scale (1-6), while bases have high values (8-14). Acids turn litmus red; bases turn it blue.

Typical strong acids are sulfuric acid and hydrochloric acid; less strong acids are acetic acid (vinegar) and citric acid (vitamin C).

Sodium hydroxide (NaOH) is a common strong base; aluminum and magnesium hydroxides are weak bases, used as antacids (so called because they neutralize digestive acids present in the stomach).

Phosphorus

A nonmetallic element. Reactive; white phosphorous is pyrophoric, that is, it "bursts into flames on contact with air" (Zumdahl, 864). Forms compounds with oxygen and halides.

Ribose Sugar

Deoxyribose Sugar

Figure 23.21

The structure of the pentoses (a) deoxyribose and (b) ribose. Deoxyribose is the sugar molecule present in DNA; ribose is found in RNA.

Phosphate

This is a phosphorus atom surrounded by four oxygen atoms. The presence of phosphates account for the phosphorus found present earlier, as well as the negative charge of DNA.

Bases

Around the turn of the century, the five bases important to DNA and RNA had been identified: guanine, adenine, cytosine, thymine, and uracil.

Keto**Enol**

-Keto and enol forms exist in solution as rapidly interconverting structures. The difference is the placement of a hydrogen atom: in the keto configuration there is a double bond to the oxygen atom and the surrounding carbons are bonded to four hydrogen atoms; in the enol configuration, the double bond is between carbon atoms, and the hydrogen displaced onto oxygen.

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